## REMARKS/ARGUMENTS

Favorable reconsideration of this application as presently amended in light of the following discussion is respectfully requested.

Claims 1-18 are now pending in this application. In the outstanding Office Action, claims 1-18 were rejected under 35 U.S.C. § 102(e) as anticipated by Takenaka, U.S. Patent No. 6,243,623. The Abstract was objected to.

Claims 1-18 were rejected under 35 U.S.C. § 102(e) as anticipated by Takenaka, U.S. Patent No. 6,243,623. These rejections are respectfully traversed, as the Office has not stated a prima facie case of anticipation.

The present invention is directed to methods and apparatuses for walking control of robots. Conventionally, the walking motion of a legged robot was attempted by a gait generation device such as the one shown in Takenaka and JP-A No. 11-300660 (US Patent 6,289,265). Joint angle commands were planned for each joint to realize a desired gait and motion. The joint angle commands were executed and performed accurately by actuators incorporated in the joints of the legged moving robot, resulting in walking motion. However, it is extremely difficult to realize stable walking by merely accurately executing the joint angle commands that are planned by the gait generation device because the actual walking environment is not identical with the environment assumed by the gait generation device. Moreover, the attitude of the legged moving robot is affected by such things as unexpected road surface environment (such as projections and depressions), potentially causing the robot to topple over. Accordingly, it is necessary to have a walking control apparatus which uses information fed from various sensors such as an attitude sensor and a joint angle sensor, and

compensates, in real time, the joint angle commands planned by the gait generation device so

as to achieve stable gait.   The scheme for such an apparatus is described in Fig. A, below.

FIG. A
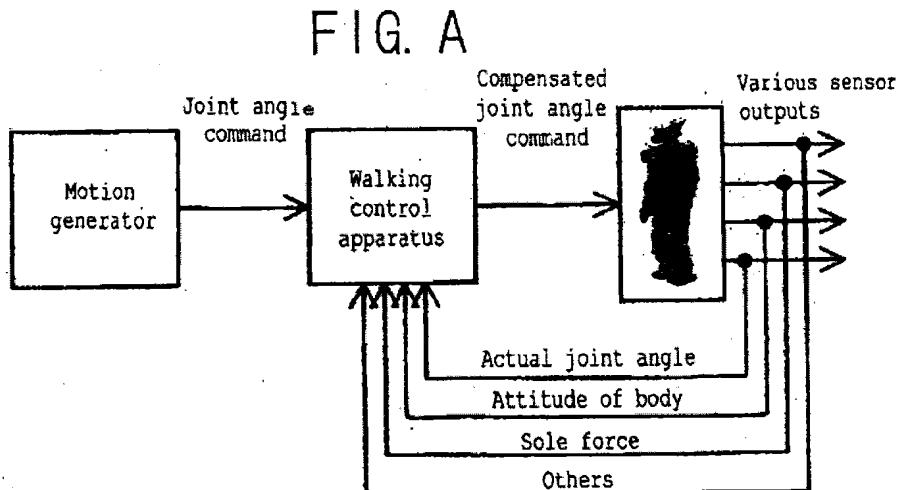
The walking control apparatus receives motion descriptions (or joint angle commands)

generated by a motion generator (or gait generation device). The walking control apparatus

feeds back information fed from various sensors such as the attitude sensor and the joint

angle sensor so as to compensate, in real time, the joint angle commands that describe the

motion for performing a stable walking control.

Further, in a control device for a conventional legged moving robot, a stable control

system is designed based on the orthogonal coordinate system, or moving-direction

coordinate system. An orthogonal coordinate system having one axis in a moving direction is

illustrated in Fig. B below:

FIG. B

X-axis

Right leg
(in air)

Y-axis   Left leg   Moving direction
(contacting ground)
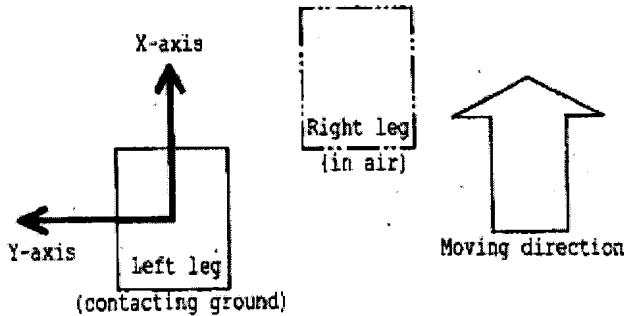
(a) Top view of soles of walking legged robot
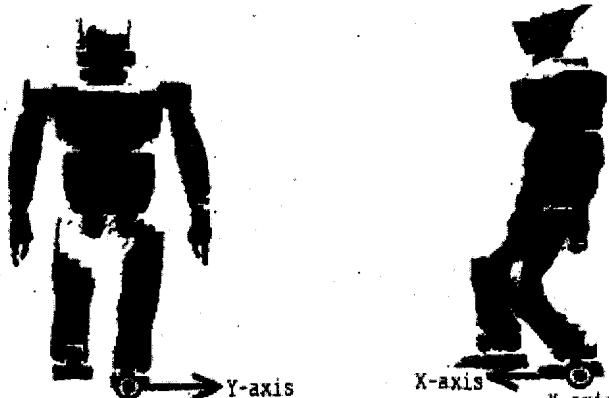
Y-axis
X-axis   X-axis   Y-axis
(b) Front view of walking legged robot   (c) Side view of walking legged robot
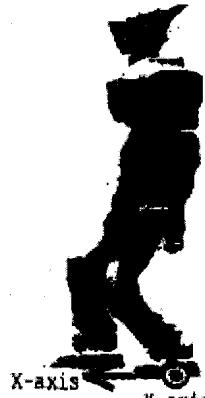
The legged moving robot in the Takenaka reference comprises such an coordinate system.

This control system, with a moving-direction coordinate system, is appealing as a system

design approach because it matches the human intuition when motion details of the robot are

designed. However, with the control device designed by using the moving-direction

coordinate system, the attitude changes when, for example, one of the legs is moved forward.

Such a change in the attitude varies not only control parameters but also, inevitably, the

rigidity of the robot body due to the link structure of the legs affected by the attitude that

changes every moment. Accordingly, it is difficult to construct a stable walking control

system, and the control system may eventually oscillate. For example, the case of a legged

moving robot in an upright posture is illustrated by Fig. C:

FIG. C

Easy to topple over

X-axis   Y-axis
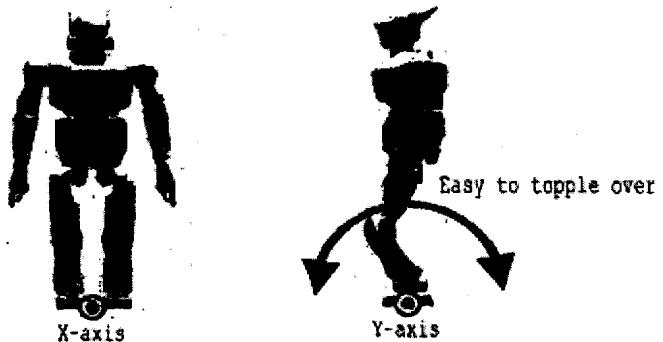
In the Fig. C case, the robot is fairly steady because the link rigidity of the legs is high in the

direction around the X-axis, which is a moving direction. However, the robot tends to topple

over in the direction around the Y-axis. One might also consider the case in which a legged

moving robot is walking on a balance beam, illustrated by Fig. D:

FIG. D

Easy to topple over

X-axis   Y-axis
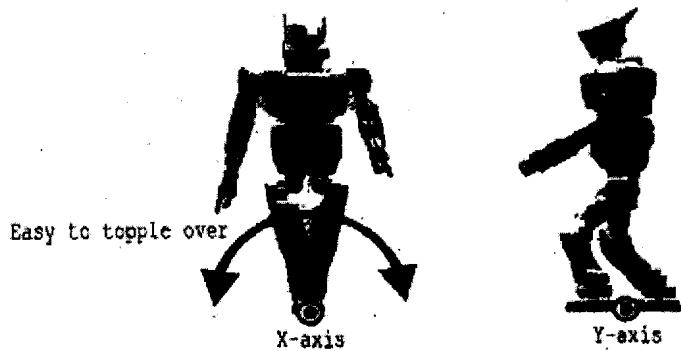
In the Fig. D case, on the other hand, the robot tends to topple over in a direction around X-

axis but hardly topples over in a direction around Y-axis because the ling rigidity of the legs

in the Y-axis direction is high. Since the link rigidity of the legs varies according to walking

patterns, it is difficult to construct a stable walking control system for a wide variety of walking patterns.

Therefore, according to the present invention, in a walking control apparatus for a legged moving robot, a coordinate system based on the sole position is defined as a control coordinate system serving as a base for walking control. Since such a coordinate system is used, the setting process required for setting dynamic parameters for walking control becomes simple, which makes the real time processing easier. Although the coordinate system is varied for dynamic walking control according to the position of soles, the calculation cost involved therein is not much different from the one involved in performing the walking control based on the conventional walking direction coordinate system.

Claim 1 is directed to a walking control method for a legged robot. In the claimed method, walking is controlled using a foot-sole coordinate system based on sole positions. The foot-sole coordinate system is based on a first coordinate axis connecting soles of the legs, a second coordinate axis perpendicular to the first coordinate axis in a horizontal plane, and a coordinate axis extending in the vertical direction. Claims 2 and 3 depend from claim 1. Claim 4 is directed to a walking control apparatus for a legged robot with a main body and legs. The claimed apparatus has a control device using a foot-sole coordinate system based positions of the soles. The foot-sole coordinate system has a first coordinate axis in a direction connecting the soles of the legs, a second coordinate axis perpendicular to the first coordinate axis in a horizontal plane, and a coordinate axis extending in the vertical direction as a control coordinate system for the walking control. Claims 5-18 depend from claim 4.

Claims 1 and 4, and each of the claims depending therefrom, are directed to a walking control apparatus or method, having a foot-sole coordinate system which is based on a first coordinate axis connecting soles of the legs, a second coordinate axis perpendicular to the

first coordinate axis in a horizontal plane, and a coordinate axis extending in the vertical

direction. This is illustrated in Fig. 2 of the present application, reproduced below.

FIG. 2
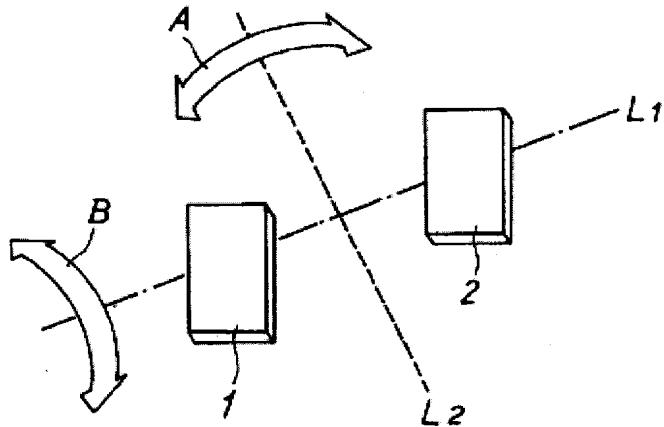
Fig. 2 shows the coordinate axis in a direction Ll (hereafter called a longitudinal

direction) connecting a pair of soles of legs, and a coordinate axis in a direction L2 (hereafter

called a transverse direction) perpendicular to the direction Ll in a horizontal plane, with a

coordinate axis in a vertical direction. As noted in the present specification, during the

walking control of the legged robot, the parameters change depending on the walking attitude

of the legged robot. In addition, the mechanical rigidities of the robot's main body and the

legs also change depending on the walking attitude. Referring again to Fig. 2, when a biped

robot walks, the rigidity in the longitudinal direction which connects the soles of both of the

ground-contacting legs is high because of the closed link structure including both legs.

Accordingly, the robot does not easily fall in the direction shown by arrow A in Fig. 2. In

comparison, in the transverse direction perpendicular to the longitudinal direction, the rigidity

is low since the closed link structure including both legs is not provided. Thus, the robot

easily falls in the direction shown by arrow B.

8

With the present invention, a control system having different control characteristics in the longitudinal and transverse directions is provided for ensuring the stability in the walking control of the legged robot. A biped walking robot has different characteristics depending on differences in the longitudinal and transverse directions, and the characteristics change.

F I G. 3

FOOT-SOLE
COORDINATE SYSTEM
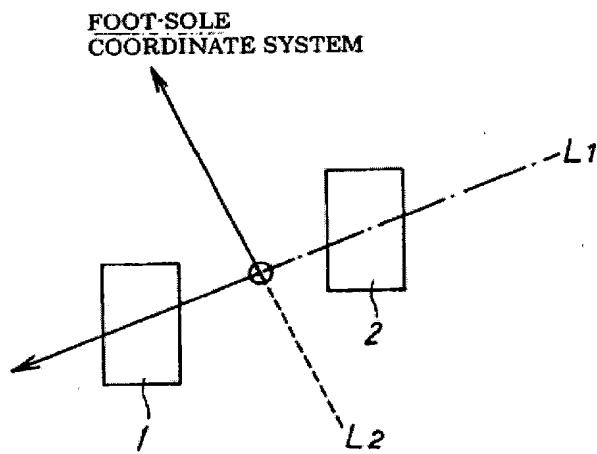
As shown in Fig. 3 from the specification, reproduced above, the walking control of the biped walking robot is performed using a foot-sole coordinate system. The system is a Cartesian coordinate system including an axis connecting the soles of the legs, as a walking control system. In the foot-sole coordinate system, the coordinate axes change dynamically since the sole positions of the robot change as the legged robot walks. When the walking control is performed, the positions of the ground-contacting legs (the left and right lower limbs 1 and 2) are detected at the time of performing control and the walking control is performed using the foot-sole coordinate system based on the direction connecting the detected sole positions of the legs.

Takenaka teaches a control system for a legged robot. However, Takenaka differs from the claimed invention. The Takenaka control coordinate system is a moving-direction coordinate system. As noted in Takenaka at least at col. 13, lines 2-10, it has a coordinate

9

axis in the direction of movement of the robot, a coordinate axis in a direction perpendicular thereto in a horizontal plane, and a coordinate axis in a vertical direction. Japanese Patent Application Laid-Open (JP-A) No. 11-300660 is described as background art in the specification of the present application. It discloses a control coordinate system similar to that of Takenaka. In fact, the prior art technology all uses this moving-direction coordinate system. The present invention, on the other hand, is not taught or suggested by the prior art.

The Office asserts in the outstanding Office Action that the claims are anticipated by Takenaka because the reference teaches the foot-sole coordinate system based on sole positions, and indicates that, for example, the line parallel to 22R(L) in Fig. 2 of the cited reference can be considered as the first axis. Applicants respectfully disagree, as the line referred to by the Office Action is one of axes in the moving-direction coordinate system, not the first axis as claimed. Moreover, it should be noted that Figs. 15 and 16 of the cited reference illustrate an arrow V of a compensating moment of two legs which might be mistaken as the direction L2 that is perpendicular to the direction Ll connecting the soles in the present invention. However, V in Figs. 15 and 16 indicate a vector, described in the Takenaka specification at col. 18, lines 16-20, and is not relevant to the coordinate system of the present invention.

In order to anticipate, a single reference must disclose each and every element of the claimed invention. Further, the reference must enable making and using the claimed invention without undue experimentation. Failing to teach a foot-sole coordinate system, with a first coordinate axis in a direction connecting the soles of the legs, Takenaka does not disclose and enable the claimed invention. Accordingly, Applicants respectfully request withdrawal of this rejection and allowance of claims 1-18.

The Abstract was objected to. Applicants herewith submit an amended abstract, and

believe the outstanding objection is obviated by same. Accordingly, Applicants respectfully

request withdrawal of the present objection.

Consequently, in light of the above discussion and in view of the present amendment,

the present application is believed to be in condition for allowance and an early and favorable

action to that effect is respectfully requested.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, L.L.P.

Customer Number

22850

Tel: (703) 413-3000
Fax: (703) 413 -2220
(OSMMN 08/09)
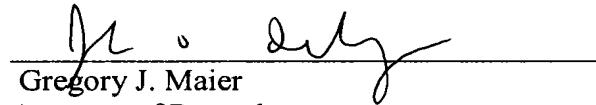
Gregory J. Maier
Attorney of Record
Registration No. 25,599

John D. Dellinger
Registration No. 50,436